OCEANS' ROLE IN CLIMATE CHANGE

INTERNATIONAL YEAR OF THE OCEAN
1998

Fisheries and Oceans Canada
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WHY STUDY THE OCEANS' ROLE IN CLIMATE CHANGE?

The oceans cover about 70% of the surface, and play an integral role in Earth's climate. Bounded by the Atlantic, Pacific and Arctic oceans, Canada is very dependent on the oceans for fisheries, transportation, energy, recreation and industry. Any change in ocean climate could have profound effects on Canada's economy and Canadians' everyday life.

Over the last 100 years or so, Earth's atmosphere has warmed 0.3 to 0.6 °C, with most of this rise occurring in the last 40 years. Although scientists do not know the exact reasons for this warming trend, strong evidence points towards the atmospheric buildup of carbon dioxide (CO_2) from the burning of fossil fuels such as coal, oil and natural gas. This human-induced warming of Earth's climate is more familiarly known as the Enhanced Greenhouse Effect.

Alarmingly, scientists are predicting that the Earth's atmosphere is likely to warm 1.0 to 3.5°C by the year 2100, an increase that could make it warmer than any time during the past 10 000 years. This anticipated warming, whether natural or human-induced, is considered one of the most serious environmental threats of our day because of potential global impacts. There is evidence that some of the abrupt climate shifts have resulted from changes to ocean circulation. Such climate changes have been traumatic for life on Earth, causing mass extinctions of a large number of animal and plant species.

In Canada, climate change could have an impact on:

- **MARINE FISHERIES** — Climate change will alter ocean temperatures, thereby affecting the geographical distributions and migratory patterns of key commercial fishery species. For example, Pacific salmon alter their migratory routes along the British Columbia coast in response to increased ocean temperatures caused by an El Niño. On Canada's east coast, lower ocean temperatures delay the arrival of Atlantic salmon to Newfoundland rivers, and may reduce fish populations.

- **COASTAL SEA LEVELS** — Coastal sea levels are expected to rise by as much as 50 cm by the year 2100 in response to melting of glaciers and thermal expansion of the oceans. Such rises could flood some coastal regions resulting in loss of coastal wetlands; negatively affect tourism, port and harbour operations and coastal towns and cities; and require expensive dikes to be constructed. While primarily affecting low- lying island states, the greatest flooding in Canada may occur in the lower Fraser River Delta in British Columbia, inland of the Beaufort Sea, Hudson and James bays, and in coastal cities such as Charlottetown, Prince Edward Island.

- **WATER RESOURCES** — Canada could experience significant changes in precipitation, evaporation, soil moisture and stream flows. These, in turn, will have an impact on agriculture, hydroelectric generation, fish and wildlife survival, marshlands, tidal zones, and ocean properties.

These and other potential future impacts have spawned national and international research programs to study Earth's natural climate system and the influence from human activities. This brochure focuses on the oceans' role in climate, highlighting key scientific findings and achievements by scientists of Canada's Department of Fisheries and Oceans (DFO).

EARTH'S CLIMATE SYSTEM — WHAT IS IT?

Climate can be defined as the prevailing conditions of Earth's physical environment. Climate terms most familiar to Canadians are average air temperature, precipitation, cloud cover, wind, frost, etc. Ocean conditions such as temperature, salinity, sea level, current systems, ice cover and biological activity are also important measures of climate.

The sun is the only significant source of heat energy driving Earth's climate system. Because Earth's surface is curved, it does not receive solar heat equally. The tropical latitudes receive the greatest amount of heat while the polar regions receive less. The resulting temperature differences between the tropics and poles drive winds and currents. These, in turn, redistribute heat and moisture around Earth.

Earth's climate is also shaped by the complex interactions between the atmosphere; the oceans and other elements of the hydrological cycle; the land; vegetation and other life; glaciers, sea and land ice; and human activities (Figure 1). Through the interaction of these major components, the climate system balances incoming solar heat and outgoing heat back to space. This has provided Earth with a remarkably stable climate. Large alterations in any of these elements, however, can upset this balance and cause dramatic changes in climate, regionally, temporarily or permanently.

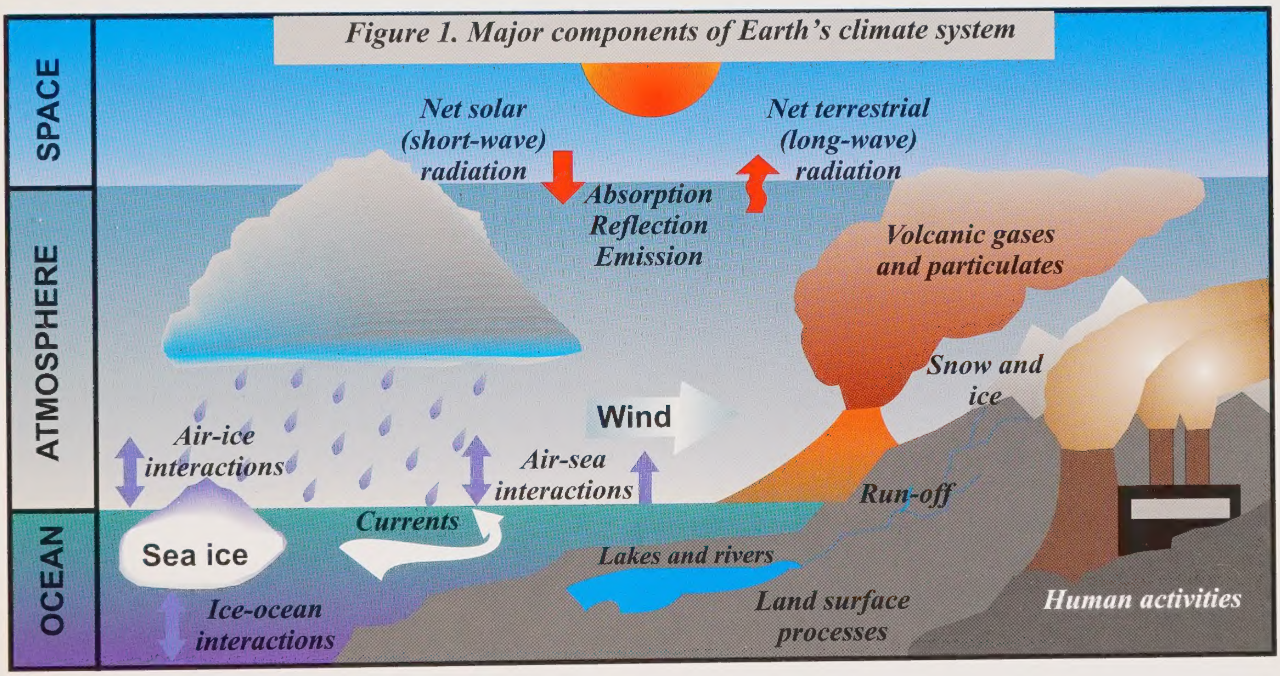


Figure 1. Major components of Earth's climate system

HOW HAS EARTH'S CLIMATE CHANGED?

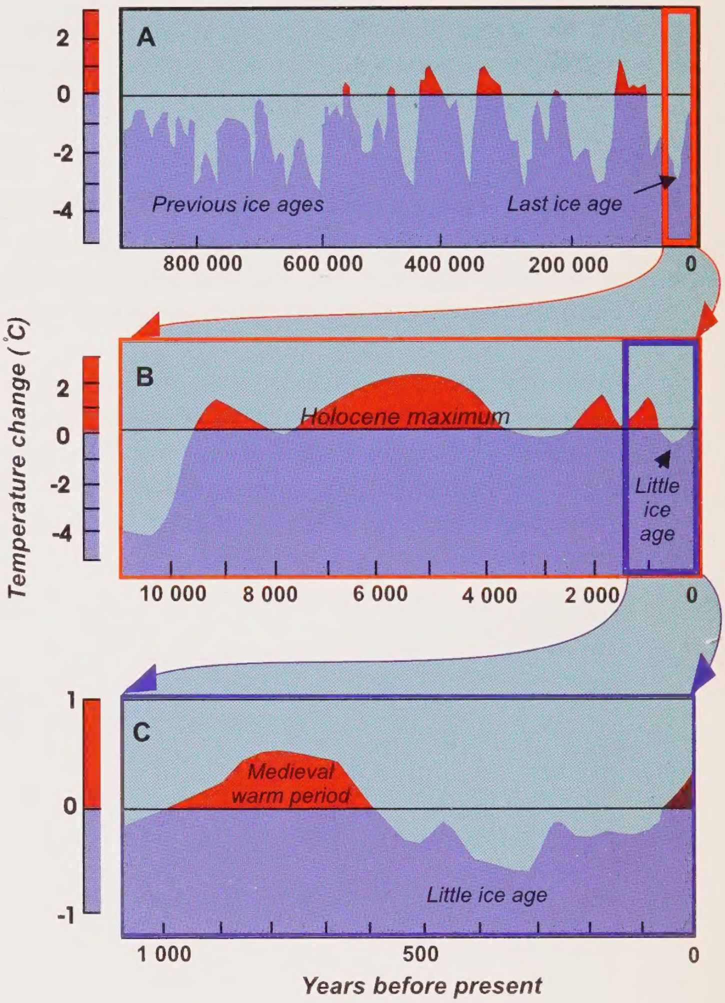
Living in temperate and polar latitudes, Canadians appreciate the natural variability of climate. The spring of one year may be characterized by raincoats and umbrellas attributable to higher than average temperatures and rainfall. The next year, spring may be remembered for lower temperatures, such that the sidewalk was cut waist deep in snow, and parkas were preferable to raincoats. Such short-term changes are a natural component of climate.

Over centuries and millennia, however, climate has been subject to more profound and widespread changes. These may have been caused by extended shifts in solar radiation, changes in position of the continents and poles, or massive volcanic eruptions. Over the last two million years, major global ice ages have occurred approximately

every 100 000 years (Figure 2-A). These ice ages are typically followed by warmer interglacial periods, such as the one Earth is in now (Figure 2-B).

During the last 9000 years, Earth's climate has remained exceptionally stable, with the global average air temperature varying only a degree or two from today's values. Evidence suggests that the current global mean temperature is at least as high as in any other century since 1400 AD (Figure 2-C).

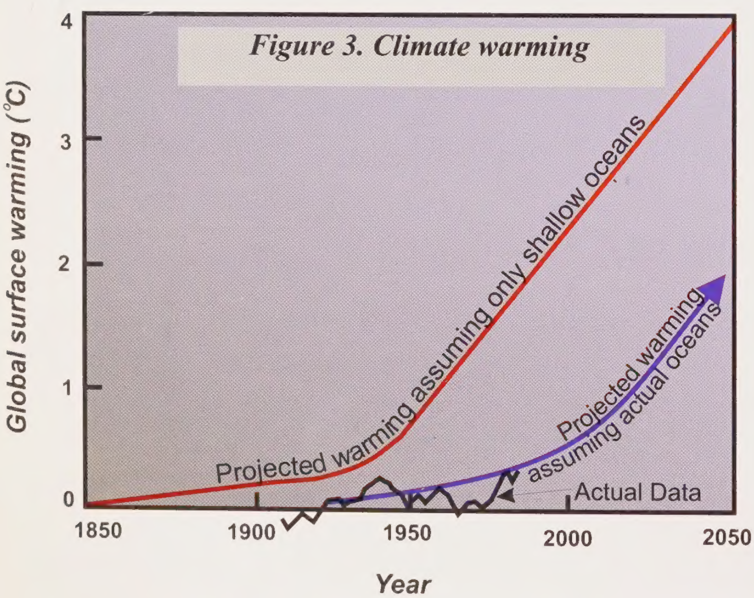
Figure 2. Global temperature changes during the past one million years



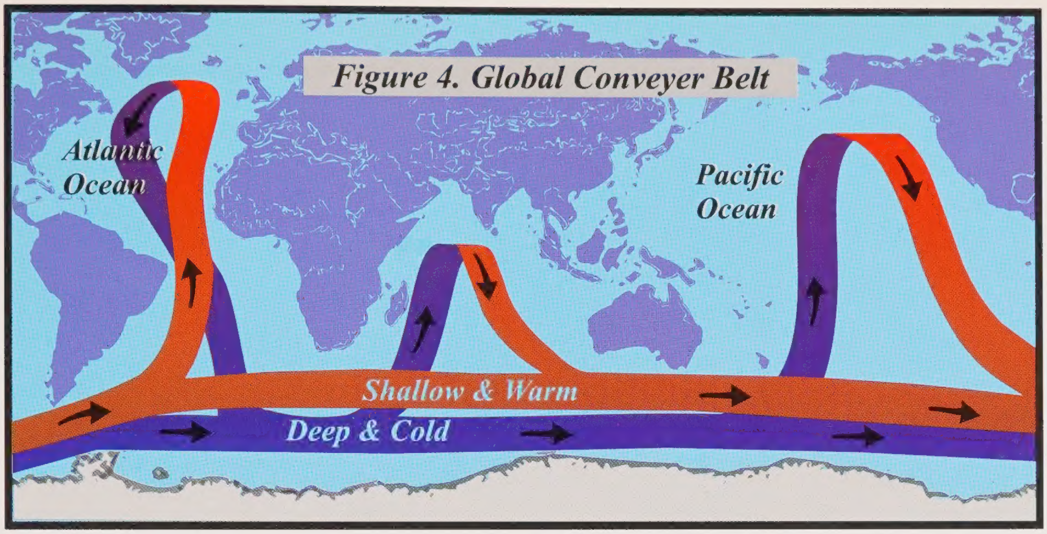
THE OCEANS — WHAT IS THEIR ROLE IN CLIMATE CHANGE?

The Oceans Store and Transport Heat

The oceans can buffer both present and long-term climate changes through their enormous capacity to store and transport heat. The ocean's capacity to store heat is at least 1000 times that of the atmosphere. Because the oceans are large and deep, they spread the effects of temperature change over great distances and depths with no measurable change to the overall temperature. So too, when an area of ocean is warmed during periods of heating (e.g., summer) or cooled (e.g., winter), it takes time for that area to revert to normal. This explains why maritime cities, such as Victoria and Halifax, experience less extreme seasonal changes than more inland cities, like Toronto or Edmonton.



If Earth's lower atmosphere was to warm as result of climate warming on a long time scale, the surface waters would also warm. However, since surface waters accumulate much of the atmospheric heat, climate warming could be delayed by up to a century. Further, since the deep waters of the ocean represent more than 75% of the ocean's volume and heat capacity, it will take centuries for these waters to respond fully to climate warming (Figure 3). Likewise, if the cause of warming was removed, it would take centuries for the oceans to return to their original state. Earth's oceans transport great amounts of salt and heat via the Global Conveyer Belt (Figure 4). Equatorial oceans absorb heat from the sun. In the Atlantic, the wind-driven Gulf Stream carries this heat north to the Carolina's, warming the climate of the east coast of North America along the way.



These warm waters continue eastward and northward across the North Atlantic warming the air and producing a climate in Europe that is surprisingly mild for its latitude. This normal exchange of heat between the atmosphere and oceans, however, is occasionally altered resulting in dramatic effects on regional and global climates. For example, the El Niño phenomenon, results when warm surface water in the equatorial Pacific moves eastward (see inset).

As surface waters move north in the Atlantic, they cool, become denser and sink to the ocean bottom. This sinking process is called deep water formation and is pivotal to the oceans role in climate. Deep currents (illustrated in blue) carry these deep North Atlantic waters into the Antarctic Circumpolar Circulation from which it spreads northward into the Pacific and Indian Oceans. Over many decades, it slowly rises into the upper layers, absorbs heat from the sun and eventually returns to the North Atlantic as warm surface water to begin the cycle again. The net result is oceanic transport of heat from the tropics to the temperate and polar regions of the globe.

The Oceans Absorb Carbon Dioxide

Atmospheric CO_2 is one of the main gases responsible for trapping heat and keeping Earth warm. The amount of atmospheric CO_2 is a balance of the exchange of CO_2 in the Global Carbon Cycle (Figure 5). The oceans play an integral role in this cycle because of their large capacity to absorb CO_2. If the oceans had no such CO_2 storage capacity,

THE EL NIÑO PHENOMENON

Normally, trade winds over the Pacific Ocean blow from east to west along the equator and push warm surface waters towards Indonesia. A bulge of warm water is created as the surface waters pile up near Indonesia. Over this bulge, warm moist air rises, moves eastward and sinks over Peru and Ecuador. This circulation results in high rainfall (tropical rainforests) in Indonesia and dry, desert conditions along South America's coastal plain.

Every few years, however, the trade winds slacken or reverse and the accumulated bulge of warm water off Indonesia begins to move back across the Pacific to the coast of South America. The bulge of warm water carries with it moist air, clouds and rain. When the bulge hits the coast of South America, an El Niño has started. It begins with rain in the coastal desert of South America, a sea level rise by about 30 cm and an increase in sea surface temperature by 6 to 8°C. As the bulge of warm water hits the coast of South America, it is deflected north and south away from the equator. These warm waters eventually reach Canada's west coast greatly affecting climate and fisheries. For more information, please refer to Fisheries and Oceans Canada Institute of Ocean Sciences fact sheet on El Niños.

there would be nearly 70 times more CO_2 in the atmosphere than during pre-industrial times, and result in an average air temperature of 35°C, or about 20°C higher than present. Animal and plant species as we currently know them would cease to exist.

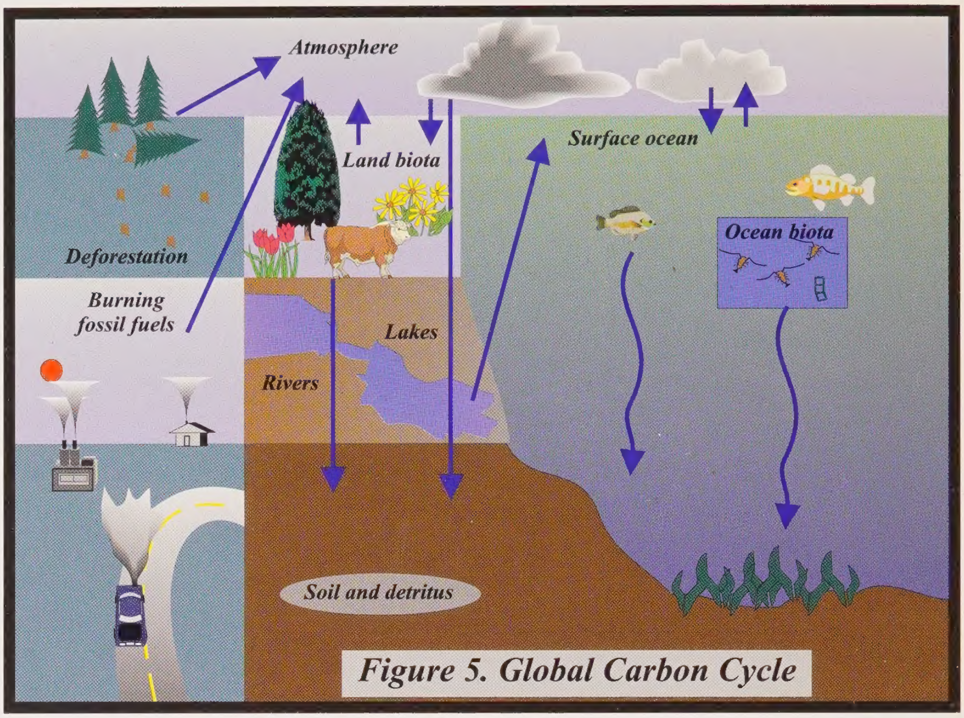


Figure 5. Global Carbon Cycle

The Global Carbon Cycle has a natural balance where, over time, there is no net addition of CO_2 to the atmosphere. However, human activities, such as the burning of fossil fuels, are altering this natural balance. Canadians rank 8th among the world's CO_2 consumers, averaging almost 17 tonnes per person per year.

Scientists estimate that a doubling of atmospheric CO_2 concentrations of pre-industrial levels is highly likely by the year 2100. This, in turn, could increase Earth's average air temperature by 1.0 to 3.5°C. Surprisingly, atmospheric CO_2 levels are rising more slowly than expected. Nearly 50% of CO_2 from human activities that should be in the atmosphere is missing. The oceans are believed to be the main sink for this missing CO_2, which could delay possible climate warming caused by the atmospheric buildup of CO_2 emissions. How do the oceans absorb atmospheric CO_2? Initially, CO_2 is absorbed at the air-sea interface. Here, the relative amount of CO_2 held in the atmosphere and dissolved in the surface waters determines whether the oceans absorb more CO_2 or emit it back to the atmosphere. As the level of CO_2 in surface waters increases, the absorbing capacity of the oceans decreases.

Within seconds of entering the surface waters, CO_2 gas undergoes several chemical reactions. Only 1% remains as dissolved CO_2 gas. Most CO_2 (85%) ends up as bicarbonate, familiarly known as baking soda. The remainder is tied up as carbonate ions that further react with calcium to produce calcite — the building block for shells of marine animals. Because of these chemical reactions, the oceans can hold up to 60 times more CO_2 than the atmosphere.

Biologically, CO_2 is also removed from surface waters by marine phytoplankton during photosynthesis. When the phytoplankton die or are eaten by zooplankton, the CO_2 is converted into fecal pellets, calcareous shells or bones, and plant fragments that eventually sink into the deep ocean. Pre-industrial atmospheric CO_2 levels would likely have been twice as high if the ocean was lifeless.

Over a longer time scale, CO_2 is transported around the oceans by the Global Conveyer Belt (Figure 4). Initially, CO_2 is physically removed from surface to deeper waters. This occurs during deep water formation in the North Atlantic and Southern oceans. In the Pacific Ocean, CO_2 is removed to deeper waters mainly through continual downward mixing of surface waters, rather than deep water formation. Although the Global Conveyer Belt does not remove much atmospheric CO_2 per year, a very large amount is transported over centuries of absorption. While cycling through the Conveyer Belt, CO_2 may be out of contact with the atmosphere for as long as 1000 years before it escapes back to the atmosphere at areas of ocean upwelling.

The Arctic Ocean is a Linchpin to Earth's Climate System

Most people wrongly think of the Arctic Ocean as a quiet and isolated sea with little global importance. However, ongoing climate research is dispelling this view. In fact, the Arctic Ocean plays a critical role in shaping global climate in some of the following ways:

The albedo-feedback effect — Clouds, aerosols and Earth's surface together reflect about 30% of the incoming solar heat back to space. Arctic and Antarctic sea ice and glaciers are responsible for most of this reflection because they have high albedo (reflectivity). For example, if snow and ice were to decrease, global albedo would be lower and more solar energy would be absorbed at Earth's surface. This would increase global temperatures and melt even more Arctic snow and ice. The result is a spiralling increase in temperatures.

The insulator effect — Arctic sea ice acts as a barrier to heat exchange between the oceans and the atmosphere. Arctic sea ice and surface layers of cold fresh waters prevent deeper warm waters from the North Atlantic from transferring their heat to the atmosphere as they reach the Arctic. For example, if snow and ice cover were to increase, Arctic temperatures would decrease, thereby driving further sea ice creation. This, in turn, increases albedo and reflects more heat back into space.

The thermohaline (temperature, salinity) throttle effect — In the Arctic Ocean, fresh water from the melting of sea ice decreases the salinity and density of the surface waters while the freezing of seawater to ice increases the salinity. These changes in density influence the strength of thermohaline circulation (Global Conveyer Belt) in the North Atlantic Ocean by operating much like a throttle in an engine and, in turn, profoundly affect global ocean circulation patterns. For example, if an abnormally high amount of Arctic freshwater enters the North Atlantic, the reduced density of surface waters could stall deep water formation. This would reduce the poleward transport of heat by surface currents that normally replace the sinking deep water. This weakening of deep water formation occurred in the 1960s during a period referred to as the "Great Salinity Anomaly".

Canadian Scientists — Leaders in International Climate Research

Climate research by DFO scientists has greatly advanced our understanding of the ocean's role in climate. These findings are often part of larger, international research and monitoring programs, such as the World Climate Research Programme, World Ocean Circulation Experiment, Joint Global Ocean Flux Study, Arctic Climate System Study and Global Ocean Ecosystem Dynamics. Some important scientific findings by DFO scientists are summarized below.

- ***Ocean's biological uptake of CO_2*** — DFO scientists made the first contemporary estimate of global ocean primary productivity. Their estimate is almost double previous assumptions, suggesting a more important role for the ocean's plants and animals in the global CO_2 cycle.

- ***Ocean's uptake of human-made CO_2*** — DFO scientists, in collaboration with the United States and Australia, produced the first present-day evidence of a net uptake of atmospheric CO_2 by the oceans. This confirms that the oceans are the dominant net sink for CO_2 generated by human activities. This net uptake of CO_2 is an estimated two billion tonnes per year, or 40% of the total CO_2 emissions from the burning of fossil fuels and wood. DFO scientists report that fossil-fuel CO_2 has penetrated 400 to 1200 metres into the North Pacific Ocean depths, at a rate of 30 metres per year. The capacity of the CO_2 uptake in the oceans is not limitless and is controlled by the amount of calcite in the ocean. Further, this capacity is decreasing at relatively fast rates in Earth's oceans.

- ***Changes in the Labrador Sea*** — In the late 1960s, DFO scientists first described a change in the strength of deep water formation in the Labrador Sea (one of only three such deep water formation areas in the world). These changes, caused by an excess of precipitation and runoff over the North Atlantic, could result in all deep water being formed in the Antarctic Ocean and result in enormous changes to global ocean circulation patterns and climate.

- ***Changes in the Arctic Ocean*** — Results from the first-ever oceanographic crossing of the Arctic Ocean revealed that the temperature of the Atlantic layer of water entering the Arctic Ocean has increased by as much as 1°C during the 1990s. DFO scientists identified a shallow circulation between the continental shelves and basins of the Arctic Ocean. This circulation is driven by ice formation, which isolates existing ice from warm waters from the North Atlantic. This is an important feedback loop in the climate system.

- ***Climate influences on fisheries*** — DFO researchers report that the sizes of 4-year-old Atlantic cod off the United Kingdom and on Georges Bank are 10 times bigger than those off Newfoundland and in the Gulf of St. Lawrence. This is due to difference in regional climates. They also learned that periods of cold ocean temperatures have been shown to affect the growth rate and spawning of capelin in Newfoundland waters. Cooling of conditions in the northwestern Atlantic Ocean has contributed to the decline in Atlantic fish stocks (including Northern Cod) in the 1990s. In the Pacific Ocean, a warming trend since the 1970s was followed by a doubling in salmon production, which appeared to be related to major changes in the survival and growth rates of all species of Pacific salmon.

CREDITS AND ACKNOWLEDGMENTS

This brochure was written by Allen Eade, Alopex Consulting, Victoria, B.C., and graphics and design were produced by Robert Bowen, Diversified Scientific Solutions, Victoria, B.C., using funds from Canada's Green Plan. Financial support for the Ocean Climate Research, upon which much of the material in this brochure was taken, was obtained from Fisheries and Oceans Canada, the Green Plan Ocean Climate Program and the Program for Energy Research and Development (PERD). Support and guidance for this brochure were provided by Brian Smiley, DFO Sidney, and Jim Powell, DFO Ottawa. The following DFO scientists provided guidance on the selection of resource material for this brochure and their comments were greatly appreciated: Pacific Region — C. S. Wong, Ed Carmack, Humfrey Melling, Keith Johnson, Ken Denman, Howard Freeland, Frank Whitney. Maritimes Region — Ken Drinkwater, Allyn Clark, Glen Harrison, Dan Wright. Laurentian Region — Alain Vezina. National Capital Region — Dick Stoddart, Iola Price.

Figure 4 is a schematic representation of the Global Conveyor Belt. A more complete explanation of this oceanic circulation can be found in NATURE, Vol. 382, August 1996.

Cover photos supplied by Tom Juhasz.

Published by:
Communications Directorate
Fisheries and Oceans Canada
Ottawa, Ontario
K1A 0E6
DFO/5566

Cat. No. Fs 23-338/1998E
ISBN 0-662-26618-8

Printed on Recycled Paper